Microwave Performance of AlGaN/GaN Metal Insulator Semiconductor Field Effect Transistors

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In our previous effort, we have shown a significant reduction of the so-called "DC-to-RF dispersion" in undoped AlGaN/GaN high electron mobility transistors (HEMTs) when passivated post-processing with plasma-enhanced chemical vapor deposition (PECVD) Si_3N_4[1]. As a result these devices on sapphire achieved 4.0 W/mm of output power (P_{out}) with 41% power added efficiency (PAE) at 4 GHz. A recent study further suggests that Si_3N_4 as an insulating passivating film provides a fixed positive charge, which balances out the AlGaN polarization charge and prevent surface related two-dimensional electron gas (2DEG) depletion to occur[2]. With these developments, a process was developed to fabricate metal insulator semiconductor field effect transistors (MISFET) devices from surface-passivated undoped AlGaN/GaN heterostructures on 2" diameter sapphire substrates.

These structures which exhibited mobilities of around 1125 $cm^2/V{\cdot}s$ for 2DEG densities of $1.1{\cdot}10\ cm^{-2}$ were coated with 30-nm Si_3N_4 through a commercial deposition system[3]. A gate recess process via dry etching was adopted to thin down the dielectric layer to roughly 20-nm. For a comparative study, conventional HEMTs without gate recess were also processed from unpassivated AlGaN/GaN heterostructures with similar mobilities and 2DEG density. Significant differences between the devices amounted to the ohmic metallization and annealing conditions which resulted in transfer resistances for the MISFETs (unpassivated HEMTs) of around 1.2 -mm (0.3 -mm). Otherwise, the remaining processing conditions used for either device is similar when applicable. Gate dimensions for all these devices were 100 µm x 0.6 µm.

Typical DC output characteristics for both the MISFET and unpassivated HEMT are shown in Figure 1. Because of the relatively large transfer resistance, a knee voltage of 6 V were typically measured for the MISFETs as compared to 3 V for the unpassivated HEMTs. However with a slightly larger separation of the 2DEG from the Schottky metal by the 20-nm dielectric layer, the pinchoff voltage is extended to –10 V from the –6 V typically observed in the unpassivated HEMTs. Furthermore, these MISFETs exhibit a transconductance (g_m) profile that is slightly reduced but at the same time broader compared to the unpassivated HEMT with peak g_m of 110 (130) mS/mm for the MISFET (unpassivated HEMT). Such a profile for the MISFET should provide a larger gate voltage swing and thereby improve the dynamic range for power and linearity. Nevertheless, full channel currents of around 750 (700) mA/mm at +2 (0) V on the gate was measured for the MISFET as compared to 680 mA/mm at zero gate bias for the unpassivated HEMT.

Pulsed and static transfer characteristics at 7.0 V drain bias were measured for both the MISFET and unpassivated HEMTs as a means to identify the DC-to-RF dispersion introduced in field effect transistors from the interaction between channel electrons and surface states. As shown in Figure 2, the pulsed drain current of the MISFET matches that of its static curve closely at all gate voltages above pinch off. This is in contrast to the unpassivated HEMT where the pulsed full channel current reaches only 40% of the static full channel value. These pulse drain currents represents the maximum current flowing during RF operation and should therefore allow MISFETs to achieve higher microwave performance over the unpassivated HEMTs. In fact, class A power sweeps at 4 GHz with 20, 25 and 28 V bias for the device of Figure 1 exhibit maximum P_{out} from 2.8 W/mm to 4.2 W/mm with PAE of 35-37% (see Figure 3). These power densities are within 10% of those predicted from the static I-V curves and suggest that these devices do no suffer from the DC-to-RF dispersion, corroborating the results from the pulsed gate measurements. In contrast, unpassivated HEMTs do suffer from the DC-to-RF dispersion as the maximum P_{out} are typically 25% lower than what is expected from their static I-V's at 15.0 V (1.5 W/mm measured as opposed to 2.1 W/mm expected). Microwave performance of similar MISFETs on semi-insulating SiC will also be presented.

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[1] B. M. Green, K. K. Chu, E. M. Chumbes, J. A. Smart, J. R. Shealy and L. F. Eastman, "The effect of surface passivation on the microwave characteristics of undoped AlGaN/GaN HEMTs," *IEEE Electron Device Lett*., June 2000.

[2] T. Prunty, J. A. Smart, B. K. Ridley, L. F. Eastman and J. R. Shealy, "Passivation of AlGaN/GaN heterostructures with silicon nitride," *Appl. Phys. Lett*, submitted.

[3] R. S. Rosler and G. M. Engle, "LPCVD-type plasma-enhanced deposition system," *Solid State Technology*, vol. 22, p. 88-92, 1979.

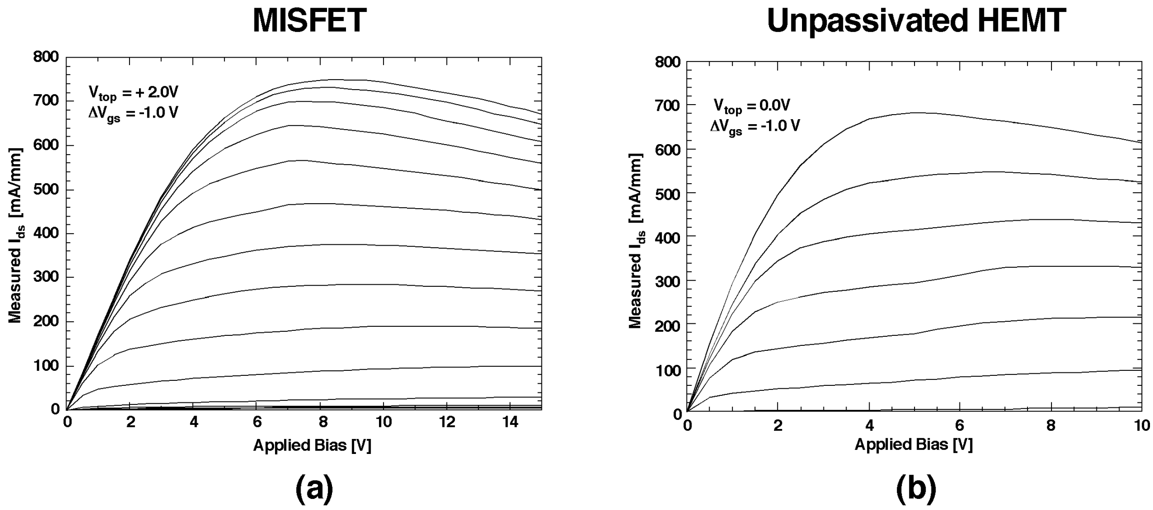

Fig. 1: Typical DC output characteristics for 100-μm (a) MISFET and (b) unpassivated HEMTs. MISFETs with a full channel current of around 750 (700) mA/mm at +2 (0) V was measured as compared to 680 mA/mm at 0 V gate bias for the unpassivated HEMTs. Pinch off voltage for the MISFETs was extended to –10 V from the –6 V typically measured in the unpassivated HEMTs as a result of the added separation of the 2DEG from the Schottky gate metal by the dielectric.

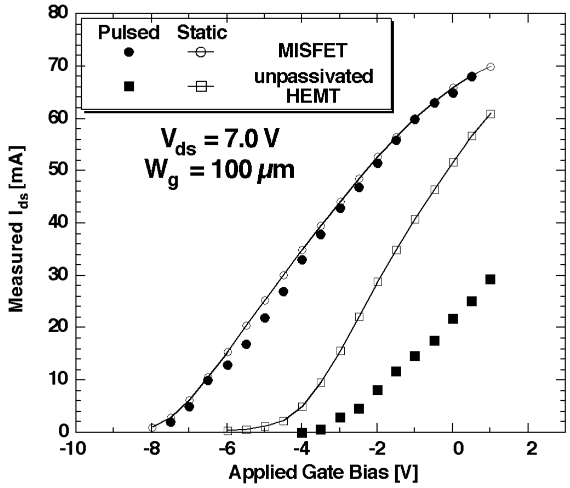

Fig 2: Pulsed and static transfer characteristics for both the MISFET and unpassivated HEMT of Figure 1 at V_{ds} = 7.0 V. Pulse conditions: 100-nsec pulses with positive polarity every 0.1-sec. Baseline was kept below pinchoff to avoid thermal effects.

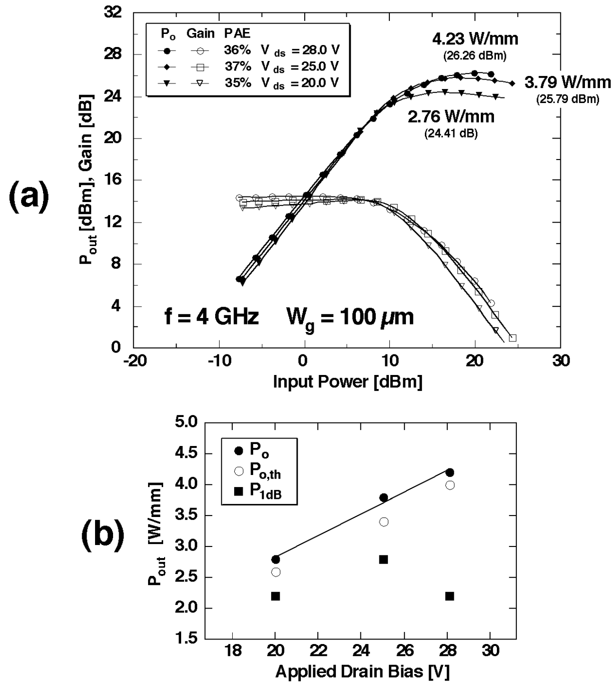

Fig. 3: (a) Power sweep curves at 4 GHz and drain biases of 20, 25 and 28 V. The maximum P_{out}'s achieved on MISFETs is 4.2 W/mm with 36% PAE at 28.0 V. (b) Summarizes the results in (a) and includes the 1-dB compression point P_{out} and calculated P_{out} from static I-V curves (Figure 1). The drop in the 1-dB compression point P_{out} at 28.0 V may result from self-heating.